PCT/DE99/01485
09/700033
529 Rec'd PCT/PTC 09 NOV 2000

6/PRTS

Method of and Apparatus for Drying Photo R sist Lay rs

The present invention relates to a method of and an apparatus for drying photo resist layers, particularly for micro system and precision mechanics technologies.

Within the general scope of manufacturing engineering in micro system and precision mechanics technologies the production of a mask by means of photo resist materials is a decisive step of process.

Photo resists are customized multi-material systems used for the production of micro electronic components, multi-layer systems and micro mechanical parts. The great variety of photographic, chemical and mechanical demands in the production process can be satisfied only by means of appropriately matched photo resists. The photo resists are multi-component systems consisting of a polymer binding agent, a photoactive component and a mixture of solvents. The polymer binding agent determines the physical properties, the photoactive component produces its effects on the photochemical process, and the mixture of solvents takes an influence on the characteristics of the resist system in the drying process. The mixture of solvents is composed in a manner that a solvent is contained which has a high steam pressure for accelerating or enhancing the stripping of the solvent mixture from the photoresist during the drying process.

The drying of the photo resists as immediate pre-stage preceding the photolithographic operation in the manufacturing process is considered a very sensitive step in the process. The physical drying of the photo resists must be so performed that a complete removal of the solvent mixture will be achieved.

In advanced manufacturing lines in the field of microelectronics the wafers are coated, as a rule, with the resist on a centred centrifuge rotating with a speed of roughly 5000 rpm. The thickness of the resist varies normally between 0.5 µm in the case of plane or planed surfaces and 2 µm with surfaces presenting distinct steps. The drying is finally performed on a hot plat at 100 °C approximately for complete stripping of the solvent. Then the photo resist is adjusted and exposed in a specific wafer exposure unit.

The period r quired for drying thicker wafers (≥ 40 μm), which are r quired in micro m - chanics in particular, lasts, as a rul , for 16 to 20 hours per lot, however, when this conventional technique is applied so that this step is a bottleneck in the production line.

Moreover, resist blisters may form during the drying process for thicker layers because for these applications the photo resist contains a high fraction of binding agent and a low viscosity. The blisters occur to an even higher extent during the drying operation in the furnace and on a hot plate. These blisters are solvent gas bubbles which remain adhered in the dried photo resist. These blisters may reach a height of several hundreds of μm and, during the subsequent exposure in the production line, extremely impair the structure resolution (proximity effect).

The European Patent EP 0 509 962 A1 discloses a method of drying photo polymers on metallised substrates, wherein the layers are dried by means of infrared radiation (IR radiation). That publication deals specifically with the so-called crawling or curtain coating in PC board technology, which permits the rapid and efficient drying of thin layers in the range of 15 μm. This method is not suitable, however, for integration into a production line for the manufacture in micro system technology. Moreover, the mere exposure of thick layers (≥ 20 μm) to IR radiation, which is required in micro system technology, does not lead to satisfactory results with respect to the surface quality of the dried layers. Compared against PC board technology, the surface quality of the photo resists is very important, however, in micro system technology for the creation of high-resolution structures.

The present invention is now based on the problem of providing a method and an apparatus which permit an operation of drying photo resist layers having a thickness of more than 20 μm within a reasonable time, which operation is integrated into the process. Furth rmore, the drying process should be suitable for various resists of different thicknesses and of different resist/substrate combinations as well as allow for the production of masks presenting a high imaging precision.

Sub A1 This problem is solved with the method and the apparatus according to the valid Patent Claims 1 and 8. Expedient embodiments are the subject matters of the dependent claims.

This method and the appertaining apparatus make it possible to achieve a dramatic reduction of the drying periods by roughly 80 % of the known drying methods, as w ll as distinct energy savings. The drying method results in homogeneous photo resists thoroughly dried

in a uniform manner, thus p rmitting a reduction of the exposure tim s for strata having rising structures.

So far, a drying technique has not become known for the micro system technology, which dries liquid photo resists having a stratum thickness of more than 20 mm and including rising structures in such a short time and with an adequate quality. The drying operation does not result in a chemical change in the resist material.

The inventive method and the inventive apparatus entail a substantial technological prerequisite for the application in micro system technology, which satisfies the demand for ever shorter periods of technological treatment of components. At the same time, the inventive method opens up the possibility of dimensionally true galvanic duplication moulding of micro-mechanical components and of building up multi-layer systems in superimposed relationship.

The inventive method and the apparatus were suitable for the manufacture of products which could so far not be produced with the achieved precision by means of any other drying method.

In the inventive method a substrate with the photo resist layer applied thereon is exposed to IR radiation in a deaerated process chamber whilst, at the same time, the temperature or a parameter dependent on temperature is measured in the vicinity of the photo resist lay r. The power of the source of IR radiation is controlled and adjusted in real time as a function of the measured temperature or the parameter dependent on the temperature, respectively (e.g. electrical resistance) for the achievement of a predetermined development of temperature versus time in the vicinity of the photo resist layer. This closed-loop control permits an optimum selection of the development of the drying condition of the layer for the resp c-tive combination of the resist material and the substrate.

The space enclosed by the process chamber may be considered the vicinity of the photo resist layer. The measurement of the temperature at a location as close as possible to the photo resist layer is preferable, however.

The development of temperature $T(t)$ (T: temperature; t: time) may be selected to be constant ($T(t) = T_0$ = const) so that the temperature do s not vary during the drying operation. The temperature level is set in corr spondence with the selected resist and substrate materials. The optimum parameters, i.e. the temperature level and the period of radiation, as

well as a possible variation of the temp rature throughout the drying p riod can be determined in an optimum manner by experimental approaches. For the temp rature l vel an upper limit must, of course, be respected above which th respectiv photo resist will be destroyed.

The inventive apparatus consists preferably of a chamber adapted to be deaerated and comprising an air inlet and an air outlet for removal of the solvents discharged from the photo resist. Inside the chamber, an IR emitter is disposed above a substrate mount, which is preferably adapted for being vertically adjusted. The substrate mount is preferably rotatable and adapted to receive several substrates at the same time. A thermometric sensor detects the temperature during the drying operation. Moreover, a controller is provided which controls the power of the IR emitter as a function of the measured temperature in such a way that a development of the temperature versus time, which can be predetermined, may be realised on the measuring site of the thermometric sensor.

The present invention will now be described in the following in more details by embodiments with reference to the drawing wherein

Fig. 1 shows an embodiment of the inventive apparatus for drying photo resist layers;

Fig. 2 represents an example of a predeterminable development of the temperature versus time, which includes a ramp;

Fig. 3 shows an example of an application of the inventive drying method in the production of pressing springs for read/write heads for hard disks;

Fig. 4 is a microscopic picture of a structure, which can be realised when the inventive drying method is applied;

Fig. 5a is a plan view of an example of a particularly expedient receiving device for accommodating substrates or wafers in the inventive apparatus; and

Fig. 5b shows a cross-sectional view of a circular single mount of the receiving device shown in Fig. 5a.

Fig. 1 is a skeleton diagram of one embodiment of an inventive IR drying system. It consists substantially of three functional elements, the furnace proper (d aeratable chamber) 1 with a receiving means 5 for accommodation of a defined number of wafers 12 having the dimensions 4" and 6", an IR radiation source 4 with the appertaining mains supply unit 9 and

the controll r modul 8. The controller module combines th controlling hardware and software as well as the necessary computing means, which are provided to control the power of the IR radiation source.

The required floor space of the total system amounts to 0.9 m² approximately for this example. The power consumption of the IR radiation source corresponds to 4 kW. The pow r to be drained can be controlled from 9 to 100 %.

The detection of the temperature is fundamentally important for a controlled process management. To this end two different thermometric sensors 6, 7 are provided in the present case. The two thermometric sensors, a pyrometer 7 and a temperature-dependent resistor 6 (PT100), may be employed as complementary elements for process management. It is understood, of course, that other thermometric sensors such as thermo elements may be used as well. It is likewise not necessary to provide two separate thermometric sensors, as in the present case. Rather one thermometric sensor is sufficient, preferably a PT100 element, which furnishes the temperature data or a measurand, respectively, to the controller module 8, which measurand presents an invariable relationship with the temperature.

Based on the drying operations so far performed by means of the illustrated system with different photo resist/substrate combinations and with different thicknesses of the photo resist layer, it has been possible to find that an IR radiation source rated for a power of 2.5 kW is sufficient for the majority of applications.

With a precise temperature measurement along the path of the IR rays being very expensive, the thermometric sensors are disposed in the present apparatus underneath the wafer mount 5 for measuring the relative temperature of the surrounding air or the surrounding gas, respectively. On the whole, temperature measurement outside the radiation, i.e. outside the region between the IR emitter and the wafer mount, is to be preferred.

In the apparatus illustrated in Fig. 1, an air inlet 2 and an air outlet or exhaust-air outlet 3 are provided in the chamber 1. An additional controllable fan 13 is arranged on the air inlet 2. The infrared radiation source 4 is adapted to be vertically adjusted by means of an adjusting means 10 via the rotatable mount 5 for the wafers 12 onto which the photo resist layer is applied. The IR radiation source 4 may be formed, for instance, of a mount for four IR tubes disposed in parallel with each other at a spacing of roughly 10 cm. The radiation source is supplied via a controllable mains supply unit 9. The power of the mains supply unit 9 is controlled by the controller unit 8.

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The receiving means 12 for accommodating wafers is formed by a rotary sample plate which r c iv s s v ral wafers in a star-shaped arrangement. In th present case, this rotary plate has a diameter of roughly 40 cm and can be rotated at a speed of 1 to 5 min^{-1} approximately. The rotating speed is equally predetermined by the controller unit 8. A speed of less than 5 min^{-1} is preferably selected in order to prevent the photo resist from spreading due to centrifugal forces. The rotary movement is created by the motor 11. The spacing of the IR radiation source from the rotary plate corresponds to 20 cm approximately in the present case. The rotation of the wafers under the radiation source expediently induces a homogeneous dying of the layers provided on the wafers, with the possibility to dry several wafers at the same time.

The air supply (cold air) and exhaust (warm air) implemented in the process leads to the establishment of a dynamic temperature equilibrium.

The plan view of Fig. 5a shows one example of a particularly expedient receiving means for accommodating substrates or wafers, respectively, in the inventive apparatus. The substrate mount (5) is made of stainless steel and, according to the present example, comprises six single mounts (14) in a star-shaped arrangement for receiving six wafers (12). It is, of course, also possible to select an arrangement including a higher or smaller number of individual mounts. For round wafers, circular rings with a recess (15) are used as single mounts so that the transfer of the wafers from a pair of tweezers into the rings will be possible. The wafers (12) are expediently supported only along the edge over a width of some 0.5 mm so that a noticeable transfer of heat to the wafer mount cannot occur.

This design of the receiving device presents, on the one hand, the advantage that the wafers (with the photo resist) can be heated in the IR ray more rapidly because of the lack of heat transfer to the mount. On the other hand, the expedient advantage is achieved that the same conditions prevail with respect to the heat transfer during each drying operation because there is no thermal coupling to the substructure. By contrast, a support over the total area on a base plate would not give rise to constant heat transmission conditions due to a possibly non-uniform support.

The sectional view in Fig. 5b shows a circular individual mount (14) of the receiving means according to Fig. 5a. The individual mount has a height of roughly 10 mm along the outer periph ry. The supporting area (16) with a wafer (12) supporting width of roughly 0.5 mm can be clearly seen in the sectional view.

The implementation of the control function with respect to the temperature in the vicinity of the layers is necessary in order to achieve proper drying results. Tests have gone to show that from the vi wpoint of a sound proc ss management a temperature variation from the predetermined temperature development by less than 0.5 °C should be observed. The precise definition and measurement of the temperature behaviour of the system as a function of the IR emitter power is the perquisite for a precise control. These values must be integrated into the control algorithm of the controller unit. To this end, a specific software is expediently applied. Hence, the advantage of flexible software control is benefited from. It is possible to predetermine or to develop and use specific control algorithms for the respective different photo resist and substrate combinations.

The controller unit makes it possible to control the IR radiation source over a power range from 0 to 100 %. Via the input of supporting locations, it is possible to implement step- or ramp-shaped temperature graphs.

Table 1 is a survey of different carrier substrates onto which a photo resist layer, 50 µm thick, could be subjected to an inventive drying operation.

In the operation of drying photo resists based on novolak, attention must be paid to the aspect, on principle, that the resist will not be modified or decomposed. The thermal stability of the photosensitive component restricts the maximum temperature which may occur during the drying operation. Photo resists on novolak basis are stable up to a temperature level of roughly 100 to 110 °C. The precise decomposing temperature of some photo resists can be determined by means of UV-VIS spectroscopy. In such an investigation the absorption spectrum of the photo resists (photosensitive component) at different drying temperatures is compared and then the decomposition is concluded via the modification. The photo resists for microelectronics and micro system technology are mostly sensitive to ultraviolet light and absorb wavelengths between 340 nm and 405 nm.

The precise determination of the reaction rate of the decomposition and evaporation reaction should be initially performed for each resist. It is very important to establish these reaction parameters for the development of drying parameters optimised in terms of time, because with such an approach the upper limits of the drying temperature and the drying time can be determined in an optimum manner.

Table 2 shows various substrate/resist combinations (comm rcially available by the designation AZ® 4562 of the Hoechst company or ma-P100 of the company of micro r sist tech-

nology GmbH) as well as combinations of different resist layer thicknesses which could be dried in an optimum manner with the drying parameters given there, i.e. emitt r pow r and dying period (time).

Substrate	thickness in µm	IR suitability
polished silicon wafer	525	positive
polished Si wafer with 100 nm Au	525	positive
Si wafer with 1 µm aluminium	500	positive
Si wafer with 100 nm oxide	525	positive
Pyrex with 100 nm Au	525	positive

Table 1

Substrate/4" silicon wafer 525 µm thick	resist type	resist thickness (µm)	drying parameters		resolution (µm)
			time(s)	emitter power (%)	
Si + Si/Au 100 nm	ma -P100	55 - 60	3600	62	10
Si + Si/Au 100 nm	ma -P100	40	3600	59	10
Si + Si/Au 100 nm	ma -P100	55	900	67	10
Si + Si/Au 100 nm	ma -P100	57	1200	67	10
Si monitor	AZ4562	32	3600	58	7
Si +´Si/Au 100 nm	AZ4562	55	3600	62	20
Si ü Si/Au 100 nm	AZ4562	100	3600	67	30

Table 2

The emitter power is related to the maximum power of 4 kW of the radiation source which is employed here. The structural resolution of the masks that can be produced from the photo resist layers subsequently is equally indicated.

Silicon wafers with nickel surfaces can be dried with the same parameters. The resist thickness in the table must be considered to correspond to the upper limit. Thinner layers can be dried within a correspondingly shorter period.

Fig. 4 illustrates one example of a created structure that could be produced by means of the mask produced from a photo resist layer dried in accordance with the present invention. For mask production a photo r sist layer, 60 µm thick, was dri d by th inventive IR drying method whereupon a mask was produced by means of photolithography and then galvani-

cally duplicated with nickel. The thickness of the webs shown in th microscopic picture amounts to 20 µm approximately.

The principal field of application of the IR drying operation are highly viscous and high-resolution photo resists. These resists are predominantly exposed by means of contact x-posing devices. Contact exposing devices operate on the shadow-casting principle. The mask structure is transferred into the resist at a ratio of 1 : 1. This means that the resolution capacity of the lithography is correlated to the distance by which the mask is spaced from the photo resist.

After IR drying the resist surface must therefore be as plane as possible so that a small spacing from the lithographic mask will be achieved. This intention, however, is confronted with the problems of marginal bead formation when the resist is centrifuged and of blister formation during the drying operation.

The cause of such a marginal bead resides in the surface tension from the resist to the substrate and in the high viscosity.

In the "spin-on" method (resist application process), the resist is applied on the centre of the wafer and the wafer is then caused to rotate. A resist layer of varying thickness is then formed as a function of time and speed of rotation. Excessive resist material remains on the wafer edge, which contracts to form a bead. This bead can be removed prior to exposure by a centrifuging process with a solvent.

The situation is different with resist blisters, which may form during the drying process. These blisters may reach a height of several hundreds of µm and therefore be extremely detrimental to the structural resolution during the exposure. Even though the blistering effect is distinctly reduced already by the IR drying operation, it can be additionally suppressed almost completely by the appropriate selection of a suitable development of temperature versus time.

To this end the photo resist is maintained in a sufficiently liquid state during the drying operation, e.g. by a continuous increase in temperature, so that any gas produced can still leave the surface of the resist. What is important is the fact that the temperature rises towards the end of the drying operation. The resist retains a sufficient viscosity ev n though some solvent is permanently evaporated.

Fig. 3 illustrates a d velopment of the temperature versus time for th suppression of a blistering effect. The temperature levels for the constant temperature range and the maximum temperature b the end of the temperature development correspond to 90 and 105 °C, for example. These values are, however, dependent on the resist materials to be dried. With application of the inventive apparatus comprising the controller unit 8 in combination with the thermometric sensors and the control of the IR radiation source it is possible, without any problems, to implement such a development through a temperature ramp. This is particularly expedient as the blistering tendency increases particularly as the thickness of the photo resist layer to be dried increases.

With the inventive method or the inventive apparatus, respectively, it is possible, for example, to manufacture pressing springs for read/write heads for hard disks with a high precision. Such a manufacturing process, which includes an inventive IR drying operation, is illustrated in Figures 3A and 3B. There a silicon wafer (diameter: 4" or 10 cm) is used as carrier substrate. A metal layer is applied onto this substrate, which acts as galvanic starter layer. Then some photo resist material is applied by centrifuging (Step No. 3), subjected to the inventive drying operation (Step No. 4), exposure and development. The micro spring is now created by a galvanic filling of the photo resist structure. In the last step, the micro spring is detached from the silicon substrate by two etching processes.

In this exemplary case, a maximum radiation power of 4 kW was equally applied. So far, it has not been possible to manufacture such pressing springs for read/write heads with the required precision.

In each of the aforedescribed embodiments, a respective IR radiation source with a power of 4 kW was employed. With appropriate drying conditions, the maximum of the IR radiation corresponds to roughly 2.6 µm. This must be understood, however, as an example only. As a matter of fact, radiation sources of different power levels and emitting at different maximum wavelengths may be employed, of course, in due consideration of each application.